

# (12) UK Patent Application (19) GB (11) 2 303 215 (13) A

(43) Date of Printing by UK Office 12.02.1997

(21) Application No 9623673.2

(22) Date of Filing 11.05.1995

(30) Priority Data

(31) 24165994 (32) 12.05.1994 (33) US

(86) International Application Data  
PCT/US95/05780 En 11.05.1995

(87) International Publication Data  
WO95/31736 En 23.11.1995

(51) INT CL<sup>6</sup>  
G01V 3/30

(52) UK CL (Edition O )  
G1N NCLE N19B2A N19B2C

(56) Documents Cited by ISA  
GB 2268589 A EP 0475715 A FR 002651893 A  
US 4704581 A

(58) Field of Search by ISA  
INT CL<sup>5</sup> G01V 3/30

(71) Applicant(s)  
Baker Hughes Incorporated  
(Incorporated in USA - Delaware)

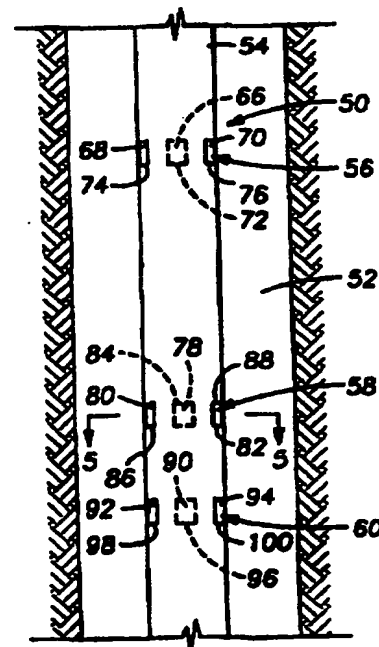
P.O.Box 4740, 3900 Essex Lane, Suite 1200, Houston,  
Texas 77210-4740, United States of America

(74) Agent and/or Address for Service  
Frank B Dehn & Co  
179 Queen Victoria Street, LONDON, EC4V 4EL,  
United Kingdom

(72) Inventor(s)  
Jian-Qun Wu

(54) Electromagnetic propagation tool using magnetic dipole antennas

(57) An electromagnetic propagation tool using magnetic dipole antennas comprising small current loops having characteristics of point dipole is presented. The electromagnetic tool comprises a drill collar segment having at least one dipole antenna for each transmitter and/or receiver antenna. The dipole antennas are disposed within pockets formed in the drill collar segment.



GB 2 303 215 A



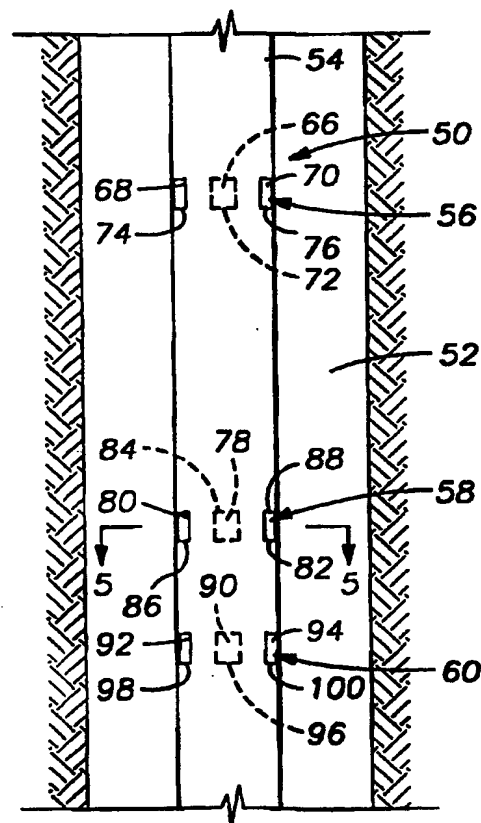
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification n<sup>6</sup>:</b> <b>G01V 3/30</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 95/31736</b> <b>(43) International Publication Date:</b> 23 November 1995 (23.11.95)
<b>(21) International Application Number:</b> PCT/US95/05780 <b>(22) International Filing Date:</b> 11 May 1995 (11.05.95) <b>(30) Priority Data:</b> 08/241,659      12 May 1994 (12.05.94)      US <b>(71) Applicant:</b> BAKER HUGHES INCORPORATED [US/US]; P.O. Box 4740, Houston, TX 77210-4740 (US). <b>(72) Inventor:</b> WU, Jian-Qun; Apartment 1408, 5100 FM 1960 West, Houston, TX 77069 (US). <b>(74) Agents:</b> ROWOLD, Carl, A. et al.; Baker Hughes Incorporated, P.O. Box 4740, Houston, TX 77210-4740 (US).		<b>(81) Designated States:</b> AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG).  <b>Published</b> <i>With international search report.</i>

**(54) Title:** ELECTROMAGNETIC PROPAGATION TOOL USING MAGNETIC DIPOLE ANTENNAS

**(57) Abstract**

An electromagnetic propagation tool using magnetic dipole antennas comprising small current loops having characteristics of a point dipole is presented. The electromagnetic tool comprises a drill collar segment having at least one dipole antenna for each transmitter and/or receiver antenna. The dipole antennas are disposed within pockets formed in the drill collar segment.



**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgyzstan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo	KR	Republic of Korea	SE	Sweden
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LU	Luxembourg	TD	Chad
CS	Czechoslovakia	LV	Latvia	TG	Togo
CZ	Czech Republic	MC	Monaco	TJ	Tajikistan
DE	Germany	MD	Republic of Moldova	TT	Trinidad and Tobago
DK	Denmark	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	US	United States of America
FI	Finland	MN	Mongolia	UZ	Uzbekistan
FR	France			VN	Viet Nam
GA	Gabon				

5 ELECTROMAGNETIC PROPAGATION TOOL USING  
MAGNETIC DIPOLE ANTENNAS

Cross-Reference to Related Application:

10 This is a continuation in part of copending U.S. Patent Application Serial No. 07/897,372 filed June 11, 1992 entitled Electromagnetic Propagation Tool Using Magnetic Dipole Antennas.

Background of the Invention:

15 This invention relates generally to borehole formation evaluation instrumentation. More particularly, this invention relates to electromagnetic propagation tools using small loop magnetic dipole antennas for use primarily in oil and gas well drilling applications.

Borehole formation evaluation tools are known which measure phase and/or  
20 amplitude of electromagnetic waves to determine an electrical property (such as resistivity or permittivity) of a section of a borehole. Typically, the existing tools used for this application are composed of one or more transmitting antennas spaced from one or more pairs of receiving antennas. An electromagnetic wave is propagated from the transmitting antenna into the formation surrounding the borehole and is  
25 detected as it passes by the receiving antennas. In a resistivity measuring tool, magnetic dipole antennas are employed which operate in the mf and lower hf spectrum. In contrast, permittivity tools utilize magnetic dipole antennas in the VHF or UHF ranges.

In a known resistivity sensor of the type hereinabove discussed, the resistivity  
30 sensor measures both phase difference and amplitude ratio to provide two

5 resistivities with different depths of investigation. A signal received in a first receiving antenna is shifted in phase and its amplitude will be less than the signal received in a second receiving antenna. Resistivities are then derived from both the phase difference and the amplitude ratio of the received signals. This differential measurement is primarily responsive to the formation opposite the receiving  
10 antennas and is less sensitive to the borehole and/or variations in the transmitted signal as in prior art sensing devices.

While well suited for its intended purposes the transmitter and receiver loop antennas suffer from several problems and disadvantages. These loop antennas generally comprise coils wrapped around the drill string. The coils are recessed in  
15 circumferentially cut grooves about the drill string. This is an attempt to protect the antenna coils from the harsh downhole environment encountered by measurement-while-drilling (MWD) tools. Even with the grooves these antenna coils are often damage during the drilling process. This has been attributed to the size of the coils required for generating and detecting the electromagnetic signals (i.e., waves).

20 The circumferential grooves tend to structurally weaken the drill string. This has two affects, firstly, the number of loop antennas in a tool is restricted by the weakening of the tool and secondly, any attempts to employ smaller diameter tools is restricted due to the depth of the circumferential grooves.

25 Summary of the Invention:

The above discussed and other problems and deficiencies of the prior art are overcome or alleviated by the electromagnetic propagation tool using magnetic dipole antennas comprising small current loops of the present invention. In

5 accordance with the present invention at least one magnetic dipole antenna is employed for each transmitter and receiver antenna of the electromagnetic propagation tool (e.g., a resistivity or permittivity tool). The magnetic dipoles are preferably aligned parallel to the centerline of the tool. Each dipole antenna has the characteristics of a point dipole. A pocket cutting is cut for each dipole antenna.

10 The small loop dipole antennas replace the larger loop antennas employed by the prior art electromagnetic propagation tools. The pocket cuttings are much smaller than the groove cuttings of the prior art (i.e., the large coil antennas). Therefore, the electromagnetic propagation tool of the present invention is mechanically stronger than the prior art tools. Further, the electromagnetic  
15 propagation tool of the present invention can be constructed to have a smaller diameter than was structurally possible with the prior art tools.

In the preferred embodiment, three small loop dipole antennas circumferentially distributed about the tool are employed for each transmitter and receiver antenna. The three dipole antenna embodiment has been shown  
20 analytically to perform at least as well as the prior art circumferentially mounted loop antenna tools, while still providing the above described advantages. A further advantage of the three dipole antenna embodiment is its capability of providing information on azimuthal variations in formation properties or tool eccentricity. The prior art circumferentially mounted loop antenna tools are not capable of providing  
25 such information. The present invention is also applicable to compensated formation measurements.

Further, the prior art circumferentially mounted loop antenna may be used in combination with the small current loop antennas of the present invention.

5           The above-discussed and other features and advantages of the present invention will be appreciated and understood by those skilled in the art from the following detailed description and drawings.

Brief Description of the Drawings:

10           Referring now to the drawings wherein like elements are numbered alike in the several FIGURES:

FIGURE 1 is a longitudinal view through an electromagnetic tool having circumferentially mounted loop antennas in accordance with the prior art;

FIGURE 2 is a longitudinal schematic view depicting the operation of an  
15 electromagnetic resistivity sensor of the prior art;

FIGURE 3 is a plan view, partly broken away, of a receiving loop antenna used in accordance with prior art electromagnetic resistivity tools;

FIGURE 4 is a longitudinal view of an electromagnetic propagation tool in accordance with the present invention;

20           FIGURE 5 is a view taken along the line 5-5 in FIGURE 4;

FIGURE 6 is a plot of amplitude ratio versus resistivity for a tool in a homogeneous formation in accordance with both the prior art and the various embodiments of the present invention;

FIGURE 7 is a plot of phase difference versus resistivity for a tool in a  
25 homogeneous formation in accordance with both the prior art and the various embodiments of the present invention;

FIGURE 8 is a plot of amplitude versus resistivity for a 6 3/4" tool in a 9 7/8" borehole with  $R_t/R_m = 100$  in accordance with both the prior art and the various

5       embodiments of the present invention; FIGURE 9 is a plot of phase difference versus resistivity for a 6 3/4" tool in a 9 7/8" borehole with  $R_t/R_m = 100$  in accordance with both the prior art and the various embodiments of the present invention;

FIGURE 10 is a plot of amplitude versus resistivity for a 6 3/4" tool in a 9 7/8" borehole with  $R_t/R_m = 0.01$  in accordance with both the prior art and the various  
10       embodiments of the present invention;

FIGURE 11 is a plot of phase difference versus resistivity for a 6 3/4" tool in a 9 7/8" borehole with  $R_t/R_m = 0.01$  in accordance with both the prior art and the various embodiments of the present invention;

15       FIGURE 12 is a longitudinal view of an electromagnetic propagation tool in accordance with an alternate embodiment of the present invention;

FIGURE 13 is a longitudinal view of an electromagnetic propagation tool in accordance with still another alternate embodiment of the present invention; and

FIGURE 14 is a longitudinal view of an electromagnetic propagation tool in  
20       accordance with yet another alternate embodiment of the present invention.

#### Description of the Preferred Embodiment:

Referring first to prior art FIGURE 1, an electromagnetic propagation resistivity tool is shown generally at 10. Tool 10 comprises a pair of drill collar  
25       segments 12 and 14. As is well known, drilling fluid or mud is pumped within the drill string as indicated by the arrows in FIGURE 1. The mud flows through a variable flow orifice 16 and is delivered to drive a first turbine 17. This first turbine 17 powers a generator which delivers electrical power to the sensors in a sensor



5 unit 18. The output from sensor unit 18, which may be in the form of electrical, hydraulic or similar signals, operates a plunger 20 which varies the size of variable orifice 16, plunger 20 having a valve driver which may be hydraulically or electrically operated. Variations in the size of orifice 16 create pressure pulses in the mud stream which are transmitted to and sensed at the surface to provide indications of  
10 various conditions sensed by sensor unit 18. This activity is directed by a microprocessor and electronics unit 22.

Since sensors in sensor unit 18 are magnetically sensitive, the particular drill string segment 12 which houses the sensor elements must be a non-magnetic section of the drill string, preferably of stainless steel or monel.

15 In drill string segment 14, a known gamma ray and resistivity electronics package 24 is also housed in a non-magnetic drill string section. Below a gamma sensor 26 is located the electromagnetic propagation resistivity sensor, which comprises a transmitting loop antenna 28 which is spaced upwardly from two spaced receiving loop antennas 30 and 32. A memory port 33 communicates with  
20 the electronics for fast retrieval of stored data when the tool 10 is brought to the surface.

Referring also to prior art FIGURE 2, the resistivity sensor measures both phase difference and amplitude ratio to provide two apparent resistivities with different depths of investigation. For example, in FIGURE 2, a two MHz wave is  
25 propagated by transmitting antenna 28 from a transmitter in the tool into the formation and it is detected as it passes the two receivers 30 and 32. The signal at the far receiver 32 is shifted in phase and its amplitude is less than the signal on the near receiver 30. Resistivities are derived from both the phase difference and the

5 amplitude ratio of the received signals. This differential measurement is primarily responsive to the formation opposite the receivers 30 and 32 and is less sensitive to the borehole and/or variations in the transmitted signals.

Turning now to prior art FIGURE 3, a receiving loop antenna 30 or 32 in accordance with the prior art magnetic resistivity measurement instrumentation of  
10 FIGURE 1 is shown. Prior art receiver 30 or 32 comprises an electrostatic shield 34 (which is preferably composed of copper) which surrounds a magnetic loop dipole antenna 36. Shield 34 includes a gap therein which is insulated using a ceramic annular plug 38. Electrostatic shield 34 also includes an exit port 40 which is located in a position opposed to insulative ceramic gap 38. Magnetic loop dipole  
15 antenna 36 exits port 40 by means of transmission line 42. In turn, transmission line 42 is connected to a radio receiver; or in some cases may be directly connected to a receiver located within the electrostatic shield 34. Alternatively, an inductive device may be used to couple the signal from loop antenna 36 to the transmission line 42 or to a radio receiver.

20 Referring to FIGURES 4 and 5, an electromagnetic propagation resistivity tool in accordance with the present invention is shown generally at 50. Resistivity tool 50 is shown in a borehole 52. Tool 50 comprises a drill collar segment 54, a transmitting antenna assembly 56 and a pair of receiving antenna assemblies 58 and 60 spaced downwardly from assembly 56. Receiver assembly 58 is commonly  
25 referred to as the near receiver and receiver assembly 60 is commonly referred to as the far receiver. Segment 54 includes an instrument housing 62 and a passage 64. It will be appreciated that drilling mud flows through passage 64 as is well known.

5 In this the preferred embodiment, antenna assemblies 56, 58 and 60 are similar and each comprises three circumferentially spaced small current loop dipole antennas aligned parallel to the centerline of tool 50, wherein each dipole antenna has the characteristics of a point dipole. Each small current loop dipole antenna has an azimuthal extent which is small with respect to the circumference of drill  
10 collar segment 54 and a longitudinal extent which is small with respect to the length of drill collar segment 54. In other words, the circumference of the small current loop dipole antennas is less than the circumference of drill collar segment 54, preferably the circumference of the small current loop dipole antenna is on the order of 10 - 20 percent of the circumference of the drill collar segment. Accordingly, the  
15 small current loop dipole antennas of the present invention will not extend completely about the drill collar, as in the prior art. Assembly 56 comprises three circumferentially spaced dipole antennas 66, 68 and 70. Each dipole antenna 66, 68 and 70 is disposed in a corresponding pocket cutting 72, 74 and 76. Assembly 58 comprises three circumferentially spaced dipole antennas 78, 80 and 82. Each  
20 dipole antenna 78, 80 and 82 is disposed in a corresponding pocket cutting 84, 86 and 88. Assembly 60 comprises three circumferentially spaced dipole antennas 90, 92 and 94. Each transmitting dipole antenna 66, 68 and 70 includes means for receiving an electrical transmit signal (i.e., an input signal). The electrical transmit signals being indicative of the electromagnetic wave propagated by corresponding  
25 antennas 66, 68 and 70. Each receiving dipole antenna 78, 80, 82, 90, 92 and 94 includes means for presenting an electrical receive signal (i.e., an output signal). The electrical receiver signals being indicative of the electromagnetic wave received by corresponding antennas 78, 80, 82, 90, 92 and 94. It will be appreciated that

5 these signals are processed in a manner entirely analogous to the prior art with the exception that each of the signals are processed in axially aligned groups, as discussed more fully below.

Each dipole antenna 90, 92 and 94 is disposed in a corresponding pocket cutting 96, 98 and 100. The circumferentially spaced pocket cuttings for each dipole  
10 antenna are an important feature of the present invention. The pocket cuttings are much smaller than the groove cuttings of the prior art (i.e., for the circumferentially mounted loop antennas). Therefore, tool 50 is mechanically stronger than the prior art tools. Further, tool 50 can be constructed to have a smaller diameter than was structurally possible with the prior art tools. Dipole antennas 66, 78 and 90 are in  
15 axial alignment with each other. Similarly, dipole antennas 68, 80 and 92 are in axial alignment with each other and dipole antennas 70, 82 and 94 are in axial alignment with each other.

The operation of the present invention is similar to that of the prior art described hereinbefore with the exception that data is provided in three segments.  
20 Each segment corresponds to each axially aligned group of dipole antennas (e.g., dipole antennas 66, 78 and 90 form one of the three axially aligned groups).

When the data from each segment is taken as a group the amplitude ratio and phase difference responses are very close to that of the circumferentially mounted loop antenna tool of the prior art. While three dipole antennas for each  
25 antenna assembly are preferred, any number of dipole antennas may be employed without departing from the spirit and scope of the present invention.

Referring to FIGURES 6 - 11, plots of amplitude ratio and phase difference are shown for the tool of the present invention having one, two and three dipole

5 antennas for each antenna assembly and for the tool of the prior art having circumferentially mounted loop antennas. As can be clearly seen from FIGURES 6 - 11 both the amplitude ratio and phase difference responses of the preferred embodiment of the present invention (i.e., tool 10 having three dipole antennas for each antenna assembly) correspond closely the responses of the prior art tool  
10 having circumferentially mounted loop antennas. FIGURES 6 and 7 illustrate the responses of a tool in a homogeneous formation. FIGURES 8 and 9 illustrate the responses of a tool in a borehole with  $R_t/R_m = 100$ , where  $R_t$  is the true resistivity and  $R_m$  is the mud resistivity. FIGURES 10 and 11 illustrate the responses of a tool in a borehole with  $R_t/R_m = 0.01$ .

15 In the preferred embodiment, with a cylindrically symmetric formation and when tool 50 is centered in borehole 52, the output signals from dipoles 78, 80 and 82 of receiver assembly 58 each have the same voltage level. The same would hold true for dipoles 90, 92 and 94 of receiver assembly 60. Further, the three voltage ratios of the three receiver dipole pairs (i.e., dipole antennas 78 and 90 are a first  
20 axially aligned pair, dipole antennas 80 and 92 are a second axially aligned pair and dipole antennas 82 and 94 are a third axially aligned pair) should be same. An imbalance in the output voltage levels of the dipoles or in the three ratios indicates that either the formation is cylindrically asymmetric or tool 50 is not centered in borehole 52 or both. The prior art circumferentially mounted loop antenna tools are  
25 azimuthally symmetric with respect to the drill string and the formation (when the tool is at the center of the borehole) and, therefore, can not provide information on azimuthal variations in formation properties.

5           The known concept of compensated formation measurements is also applicable to the present invention. Referring to FIG. 12, wherein like elements to the embodiment of FIGURE 4 are numbered alike and included a prime, a compensated dual resistivity sensor in accordance with the present invention is shown generally at 50'. Tool 50' comprises two transmitting antenna assemblies 56' and 102 which are longitudinally spaced apart on tool 50'. Also, a pair of receiving antenna assemblies 58' and 60' are symmetrically spaced longitudinally on tool 50' between transmitting antenna assemblies 56' and 102. In accordance with the known concept of compensated formation measurement each transmitting assembly 56' and 102 is operated alternately. This method of alternate operation  
10           compensates for external errors (i.e., formation errors) in the resistivity measurement.

          Assemblies 56', 58' and 60' are configured the same as 56, 58 and 60 of the FIGURE 4 embodiment, so that only assembly 102 will be described below. Transmitting antenna assembly 102 comprises three circumferentially spaced small  
20           current loop dipole antennas 104, 106 and 108 aligned parallel to the centerline of tool 50', wherein each dipole antenna has the characteristics of a point dipole. Each small current loop dipole antenna has an azimuthal extent which is small with respect to the circumference of drill collar segment 54' and a longitudinal extent which is small with respect to the length of drill collar segment 54'. In other words,  
25           the circumference of the small current loop dipole antennas is less than the circumference of drill collar segment 54', preferably the circumference of the small current loop dipole antennas is on the order of 10 - 20 percent of the circumference of the drill collar segment. Accordingly, the small current loop dipole antennas of

5 the present invention will not extend completely about the drill collar, as in the prior art. Each dipole antenna 104, 106, 108 is disposed in a corresponding pocket cutting 110, 112 and 114. Each transmitting dipole antenna 66', 68', 70', 104, 106 and 108 includes means for receiving an electrical transmit signal (i.e., an input signal). The electrical transmit signals being indicative of the electromagnetic wave  
10 propagated by corresponding antennas 66', 68', 70', 104, 106 and 108. Each receiving dipole antenna 78', 80', 82', 90', 92' and 94' includes means for presenting an electrical receive signal (i.e., an output signal). The electrical receiver signals being indicative of the electromagnetic wave received by corresponding antennas 78', 80', 82', 90', 92' and 94'. It will be appreciated that these signals are processed  
15 in a manner entirely analogous to the prior art with the exception that each of the signals are processed in axially aligned groups.

Dipole antennas 66', 78', 90' and 104 are in axial alignment with each other. Similarly, dipole antennas 68', 80', 92' and 106 are in axial alignment with each other and dipole antennas 70', 82', 94', and 108 are in axial alignment with each  
20 other.

The operation of the present invention is similar to that of the prior art described hereinbefore with the exception that data is provided in three segments. Each segment corresponds to each axially aligned group of dipole antennas (e.g., dipole antennas 66', 78', 90' and 104 form one of the three axially aligned groups).

25 Further, any imbalance in the output voltage levels of the dipoles or in the three ratios with respect to the receiver assemblies (e.g., assemblies 58' and 60' described hereinbefore) indicates that either the formation is cylindrically asymmetric or tool 50' is not centered in borehole 52' or both.

5 Referring to FIGURE 13, wherein like elements to the embodiment of  
FIGURE 4 are numbered alike and included a double prime, an electromagnetic  
propagation resistivity sensor in accordance with the present invention is shown  
generally at 50". Tool 50" comprises a transmitting antenna assembly 120 and a  
pair of receiving antenna assemblies 58" and 60" spaced downwardly from  
10 transmitting antenna assembly 120. Assemblies 58" and 60" are configured the  
same as 58 and 60 of the FIGURE 4 embodiment, so that only assembly 120 will b  
described below. Transmitting antenna assembly 120 comprises a magnetic loop  
dipole antenna of the type described hereinbefore with reference to antenna 28 of  
FIGURE 2. Transmitting dipole antenna 120 includes means for receiving an  
15 electrical transmit signal (i.e., an input signal). The electrical transmit signal being  
indicative of the electromagnetic wave propagated by antenna 120. Each receiving  
dipole antenna 78", 80", 82", 90", 92" and 94" includes means for presenting an  
electrical receive signal (i.e., an output signal). The electrical receiver signals being  
indicative of the electromagnetic wave received by corresponding antennas 78",  
20 80", 82", 90", 92" and 94". It will be appreciated that these signals are processed in  
a manner entirely analogous to the prior art with the exception that each of the  
signals are processed in axially aligned groups.

Dipole antennas 78" and 90" are in axial alignment with each other.  
Similarly, dipole antennas 80" and 92" are in axial alignment with each other and  
25 dipole antennas 82" and 94" are in axial alignment with each other.

The operation of the present invention is similar to that of the prior art  
described hereinbefore with the exception that received data is provided in three  
segments. Each segment corresponds to each axially aligned group of receiving



5 dipole antennas (e.g., dipole antennas 78" and 90" form one of the three axially aligned groups).

Referring to FIGURE 14, wherein like elements to the embodiment of FIGURE 4 are numbered alike and included a triple prime, an electromagnetic propagation resistivity sensor in accordance with the present invention is shown generally at 50". Tool 50" comprises a transmitting antenna assembly 56" and a  
10 pair of receiving antenna assemblies 122 and 122 spaced downwardly from transmitting antenna assembly 56".

Assembly 56" is configured the same as 56 of the FIGURE 4 embodiment, so that only assemblies 122 and 124 will be described below. Receiving antenna  
15 assembly 122 and 124 comprises magnetic loop dipole antennas of the type described hereinbefore with reference to antennas 30 and 32, respectively, of FIGURES 2 and 3. Each transmitting dipole antenna 66", 68" and 70" includes means for receiving an electrical transmit signal (i.e., an input signal). The electrical transmit signals being indicative of the electromagnetic wave propagated by  
20 corresponding antennas 66", 68" and 70". Each receiving dipole antenna 122 and 124 includes means for presenting an electrical receive signal (i.e., an output signal). The electrical receiver signals being indicative of the electromagnetic wave received by corresponding antennas 122 and 124. It will be appreciated that these signals are processed in a manner entirely analogous to the prior art. The operation  
25 of the present invention is similar to that of the prior art described hereinbefore with the exception that data is transmitted in three segments.

While preferred embodiments have been shown and described, various modifications and substitutions may be made thereto, without departing from the

- 5 spirit and scope of the invention. Accordingly, it is to be understood that the present invention has been described by way of illustrations and not limitations.

5 CLAIM 1. An electromagnetic propagation tool, comprising:

a drill collar segment;

transmitter means, said transmitter means being disposed on said drill collar segment, said transmitter means comprising at least one transmitting magnetic dipole antenna for propagating an electromagnetic wave, said  
10 transmitting magnetic dipole antenna comprises a small current loop dipole antenna having a circumference substantially less than a circumference of said drill collar segment; and

at least one receiver means, said receiver means being disposed on said drill collar segment at an axial distance from said transmitter means, said  
15 receiver means comprising at least one receiving magnetic dipole antenna for receiving the electromagnetic wave propagated by said transmitter means, said receiving magnetic dipole antenna comprises a small current loop dipole antenna having a circumference substantially less than a circumference of said drill collar segment.

20

CLAIM 2. The tool of claim 1 wherein said transmitting magnetic dipole antenna and said receiving magnetic dipole antenna are disposed within pockets formed in the outer surface of said drill collar segment.

25 CLAIM 3. The tool of claim 1 wherein said at least one transmitting magnetic dipole antenna comprises three circumferentially spaced transmitting magnetic dipole antennas, each of said transmitting antennas propagating the corresponding electromagnetic wave; and

wherein said at least one receiving magnetic dipole antenna comprises  
30 three circumferentially spaced receiving magnetic dipole antennas, each of said receiving antennas receiving the electromagnetic wave propagated from said transmitting antennas.

- 5 CLAIM 4. The tool of claim 3 wherein each of said three circumferentially spaced transmitting magnetic dipole antennas are in substantial circumferential alignment with a corresponding one of each of said three circumferentially spaced receiving magnetic dipole antennas.
- 10 CLAIM 5. The tool of claim 4 wherein each of said receiving magnetic dipole antennas provides an electrical output signal indicative of the corresponding electromagnetic wave received, wherein an imbalance between said output signals is indicative of at least one of cylindrical asymmetry of the formation and a deviation of a drill string from a central borehole position.
- 15 CLAIM 6. The tool of claim 1 wherein said at least one receiver means comprises two axially spaced apart receiver means, wherein said two receiver means comprises a near receiver means and a far receiver means.
- 20 CLAIM 7. The tool of claim 6 wherein said at least one transmitting magnetic dipole antenna comprises three circumferentially spaced transmitting magnetic dipole antennas, each of said transmitting antennas propagating the corresponding electromagnetic wave;
- wherein said near receiver means comprises three circumferentially
- 25 spaced near receiving magnetic dipole antennas, each of said near receiving antennas receiving the electromagnetic wave propagated from said transmitting antennas; and
- wherein said far receiver means comprises three circumferentially
- spaced far receiving magnetic dipole antennas, each of said far receiving
- 30 antennas receiving the electromagnetic wave propagated from said transmitting dipole antennas.

5 CLAIM 8. The tool of claim 7 wherein each of said three circumferentially spaced transmitting magnetic dipole antennas are in substantial axial alignment with a corresponding one of each of said three circumferentially spaced near receiving magnetic dipole antennas and with a corresponding one of each of said three circumferentially spaced far receiving magnetic  
10 dipole antennas.

CLAIM 9. The tool of claim 7 wherein each of said near receiving magnetic dipole antennas provides a first electrical output signal indicative of the electromagnetic wave received;

15 wherein each of said far receiving magnetic dipole antennas provides a second electrical output signal indicative of the electromagnetic wave received; and

wherein an imbalance between corresponding ratios of said first and second output signals is indicative of at least one of cylindrical asymmetry of  
20 the formation and a deviation of a drillstring from a central borehole position.

CLAIM 10. The tool of claim 6 wherein the axial distance between said transmitter means and said near receiver means is greater than the axial distance between said near receiver means and said far receiver means.

25

CLAIM 11. The tool of claim 1 wherein said transmitting dipole antenna is in circumferential alignment with said receiving dipole antenna.

CLAIM 12. The tool of claim 1 wherein said transmitting magnetic dipole  
30 antenna and said receiving magnetic dipole antenna are each aligned parallel to the centerline of the tool.

5 CLAIM 13. The tool of claim 1 wherein the circumference of said small current loop dipole antenna of said transmitting magnetic dipole antenna and the circumference of said small current loop dipole antenna of said receiving magnetic dipole antenna are each between about 10% and about 20% of the circumference of said drill collar segment.

10

CLAIM 14. An electromagnetic propagation tool, comprising:

a drill collar segment;

transmitter means, said transmitter means being disposed on said drill collar segment, said transmitter means comprising a transmitting magnetic

15 dipole antenna for propagating an electromagnetic wave; and

at least one receiver means, said receiver means being disposed on said drill collar segment at an axial distance from said transmitter means, said receiver means comprising at least one receiving magnetic dipole antenna for receiving the electromagnetic wave propagated by said transmitter means,

20 said receiving magnetic dipole antenna comprises a small current loop dipole antenna having a circumference substantially less than a circumference of said drill collar segment.

CLAIM 15. The tool of claim 14 wherein said at least one receiving magnetic  
25 dipole antenna comprises three circumferentially spaced receiving magnetic dipole antennas, each of said receiving antennas receiving the electromagnetic wave propagated from said transmitting antenna.

CLAIM 16. The tool of claim 14 wherein said at least one receiver means  
30 comprises two axially spaced apart receiver means, wherein said two receiver means comprises a near receiver means and a far receiver means.

5 CLAIM 17. The tool of claim 16 wherein said near receiver means comprises three circumferentially spaced near receiving magnetic dipole antennas, each of said near receiving antennas receiving the electromagnetic wave propagated from said transmitting antenna; and

wherein said far receiver means comprises three circumferentially  
10 spaced far receiving magnetic dipole antennas, each of said far receiving antennas receiving the electromagnetic wave propagated from said transmitting dipole antenna.

CLAIM 18. The tool of claim 17 wherein each of said three circumferentially  
15 spaced near receiving magnetic dipole antennas are in substantial axial alignment with a corresponding one of each of said three circumferentially spaced far receiving magnetic dipole antennas.

CLAIM 19. The tool of claim 17 wherein each of said near receiving magnetic  
20 dipole antennas provides a first electrical output signal indicative of the electromagnetic wave received;

wherein each of said far receiving magnetic dipole antennas provides a second electrical output signal indicative of the electromagnetic wave received; and

25 wherein an imbalance between corresponding ratios of said first and second output signals is indicative of at least one of cylindrical asymmetry of the formation and a deviation of a drillstring from a central borehole position.

CLAIM 20. The tool of claim 17 wherein the axial distance between said  
30 transmitter means and said near receiver means is greater than the axial distance between said near receiver means and said far receiver means.

5 CLAIM 21. The tool of claim 14 wherein said receiving magnetic dipole antenna is aligned parallel to the centerline of the tool.

CLAIM 22. The tool of claim 14 wherein the circumference of said small current loop dipole antenna of said receiving magnetic dipole antenna is  
10 between about 10% and about 20% of the circumference of said drill collar segment.

CLAIM 23. An electromagnetic propagation tool, comprising:

a drill collar segment;

15 transmitter means, said transmitter means being disposed on said drill collar segment, said transmitter means comprising at least one transmitting magnetic dipole antenna for propagating an electromagnetic wave, said transmitting magnetic dipole antenna comprises a small current loop dipole antenna having a circumference substantially less than a circumference of  
20 said drill collar segment; and

at least one receiver means, said receiver means being disposed on said drill collar segment at an axial distance from said transmitter means, said receiver means comprising a receiving magnetic dipole antenna for receiving the electromagnetic wave propagated by said transmitter means.

25

CLAIM 24. The tool of claim 23 wherein said at least one transmitting magnetic dipole antenna comprises three circumferentially spaced transmitting magnetic dipole antennas, each of said transmitting antennas propagating the corresponding electromagnetic wave.

30

CLAIM 25. The tool of claim 23 wherein said at least one receiver means comprises two axially spaced apart receiver means, wherein said two receiver means comprises a near receiver means and a far receiver means.



5

CLAIM 26. The tool of claim 25 wherein the axial distance between said transmitter means and said near receiver means is greater than the axial distance between said near receiver means and said far receiver means.

10 CLAIM 27. The tool of claim 23 wherein said transmitting magnetic dipole antenna is aligned parallel to the centerline of the tool.

CLAIM 28. The tool of claim 23 wherein the circumference of said small current loop dipole antenna of said transmitting magnetic dipole antenna is  
15 between about 10% and about 20% of the circumference of said drill collar segment.

CLAIM 29. An electromagnetic propagation tool, comprising:

a drill collar segment;

20 transmitter means comprising a transmitting magnetic dipole antenna disposed on said drill collar segment, said transmitting magnetic dipole antenna for propagating an electromagnetic wave;

at least one noncircumferential pocket formed in the outer surface of said drill collar segment at axial distance from said transmitter means, and

25 at least one receiver means comprising at least one receiving magnetic dipole antenna disposed in a corresponding said at least one pocket, said receiving magnetic dipole antenna for receiving the electromagnetic wave propagated by said transmitter means.

30 CLAIM 30. The tool of claim 29 wherein said receiving magnetic dipole antenna has the characteristics of a point dipole.

5 CLAIM 31. The tool of claim 29:

wherein said at least one pocket comprises three circumferentially spaced second pockets; and

wherein said at least one receiving magnetic dipole antenna comprises three receiving magnetic dipole antennas each disposed in a corresponding  
10 one of said pockets, each of said receiving antennas receiving the electromagnetic wave propagated from said transmitting antenna.

CLAIM 32. The tool of claim 31 wherein each of said receiving magnetic dipole antennas provides an electrical output signal indicative of the  
15 corresponding electromagnetic wave received, wherein an imbalance between said output signals is indicative of at least one of cylindrical asymmetry of the formation and a deviation of a drill string from a central borehole position.

20 CLAIM 33. An electromagnetic propagation tool, comprising:

a drill collar segment;

transmitter means, said transmitter means being disposed on said drill collar segment, said transmitter means comprising a transmitting magnetic dipole antenna for propagating an electromagnetic wave;

25 at least one receiver means, said receiver means being disposed on said drill collar segment at an axial distance from said transmitter means, said receiver means comprising at least one receiving magnetic dipole antenna for receiving the electromagnetic wave propagated by said transmitter means, said receiving magnetic dipole antenna having characteristics of a point  
30 dipole;

wherein said at least one receiver means comprises two axially spaced apart receiver means, wherein said two receiver means comprises a near receiver means and a far receiver means;

5            wherein said near receiver means comprises three circumferentially spaced near receiving magnetic dipole antennas, each of said near receiving antennas receiving the electromagnetic wave propagated from said transmitting antenna and each of said near receiving antennas having characteristics of a point dipole; and

10           wherein said far receiver means comprises three circumferentially spaced far receiving magnetic dipole antennas, each of said far receiving antennas receiving the electromagnetic wave propagated from said transmitting antenna and each of said far receiving antennas having characteristics of a point dipole.

15

CLAIM 34. The tool of claim 33 wherein each of said three circumferentially spaced near receiving magnetic dipole antennas are in substantial axial alignment with a corresponding one of each of said three circumferentially

- 5 output signals is indicative of at least one of cylindrical asymmetry of the formation and a deviation of a drillstring from a central borehole position.

CLAIM 36. The tool of claim 33 wherein the axial distance between said transmitter means and said near receiver means is greater than the axial distance between said  
10 near receiver means and said far receiver means.

CLAIM 37. An electromagnetic propagation tool, comprising:

- a drill collar segment;
- at least one noncircumferential pocket formed in the outer surface of said drill  
15 collar segment;
- transmitter means comprising at least one transmitting magnetic dipole antenna disposed in a corresponding said at least one pocket, said transmitting magnetic dipole antenna for propagating an electromagnetic wave; and
- at least one receiver means comprising a receiving magnetic dipole antenna  
20 disposed on said drill collar segment, said receiving magnetic dipole antenna for receiving the electromagnetic wave propagated by said transmitter means.

CLAIM 38. The tool of claim 37 wherein said transmitting magnetic dipole antenna has the characteristics of a point dipole.

25

CLAIM 39. The tool of claim 37:

- wherein said at least one pocket comprises three circumferentially spaced pockets; and

5 transmitter means, said transmitter means being disposed on said drill collar segment, said transmitter means comprising at least one transmitting magnetic dipole antenna for propagating an electromagnetic wave, said transmitting magnetic dipole antenna having characteristics of a point dipole;

at least one receiver means, said receiver means being disposed on said drill  
10 collar segment at an axial distance from said transmitter means, said receiver means comprising a receiving magnetic dipole antenna for receiving the electromagnetic wave propagated by said transmitter means;

wherein said at least one receiver means comprises two axially spaced apart receiver means, wherein said two receiver means comprises a near receiver means  
15 and a far receiver means;

wherein said at least one transmitting magnetic dipole antenna comprises three circumferentially spaced transmitting magnetic dipole antennas, each of said transmitting antennas propagating the corresponding electromagnetic wave and each of said transmitting antennas having characteristics of a point dipole.

20

CLAIM 41. The tool of claim 40 wherein the axial distance between said transmitter means and said near receiver means is greater than the axial distance between said near receiver means and said far receiver means.

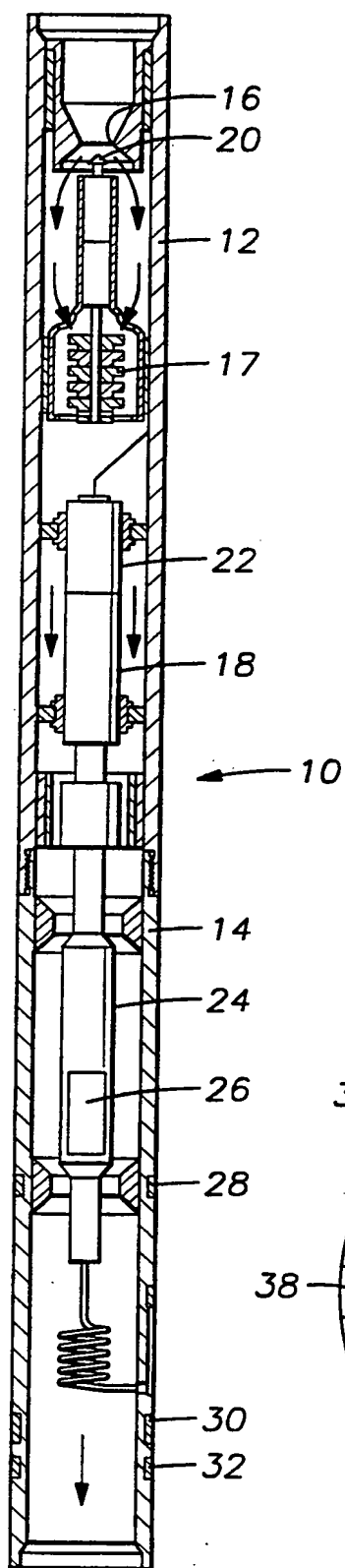


FIG. 1  
(PRIOR ART)

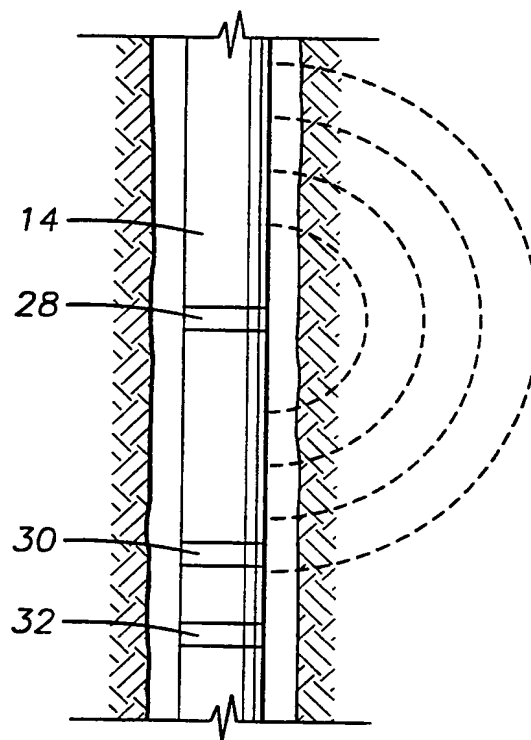


FIG. 2  
(PRIOR ART)

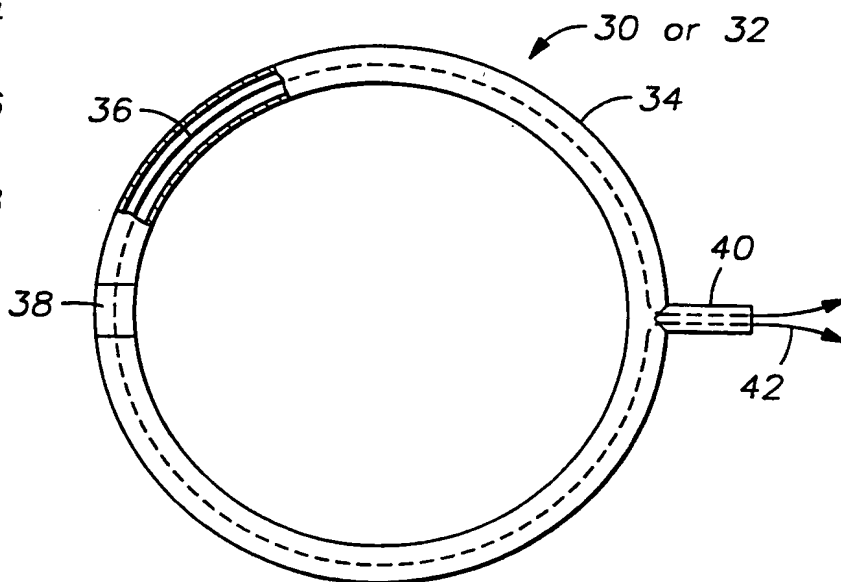


FIG. 3  
(PRIOR ART)

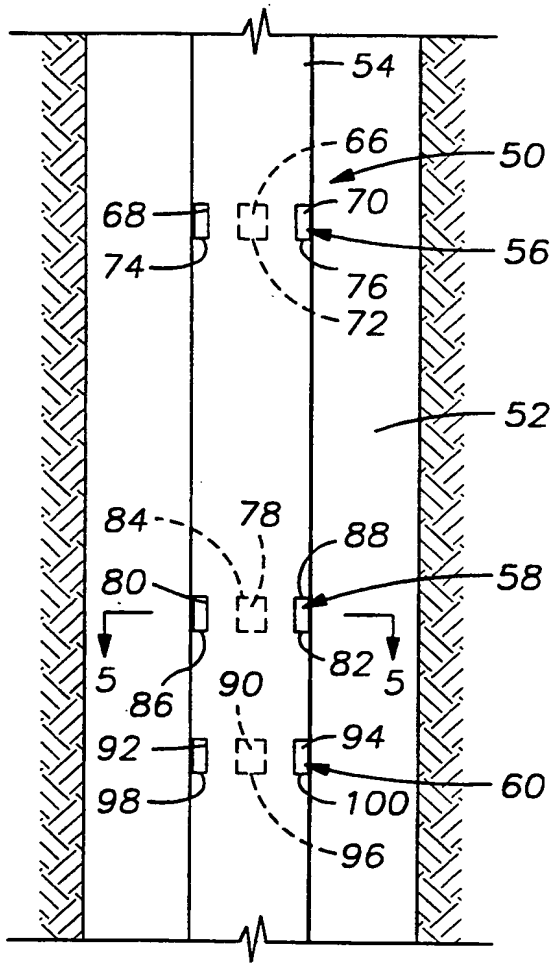


FIG. 4

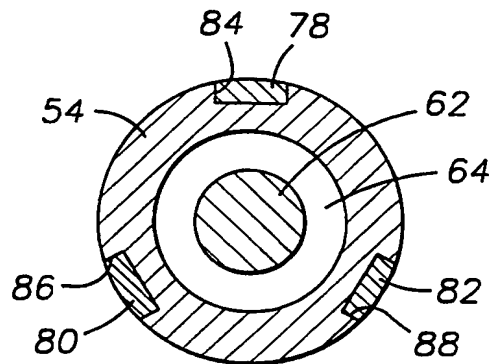


FIG. 5

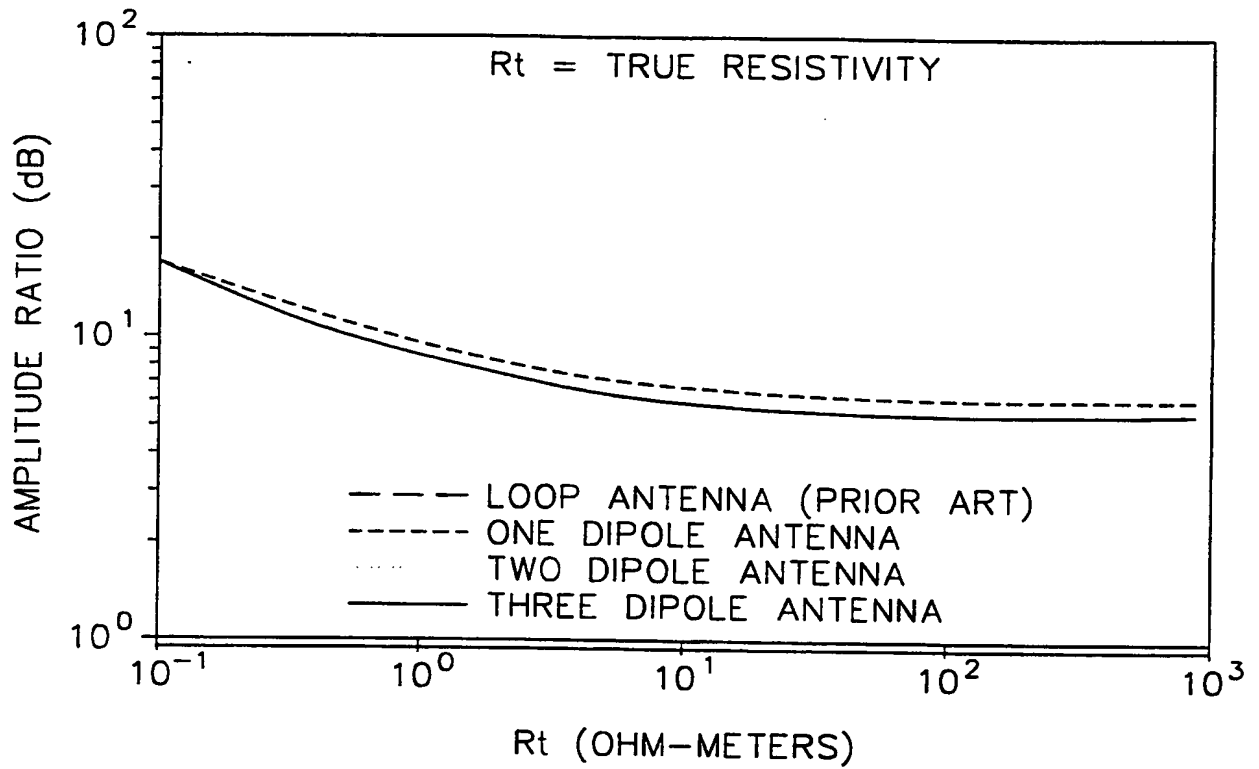


FIG. 6

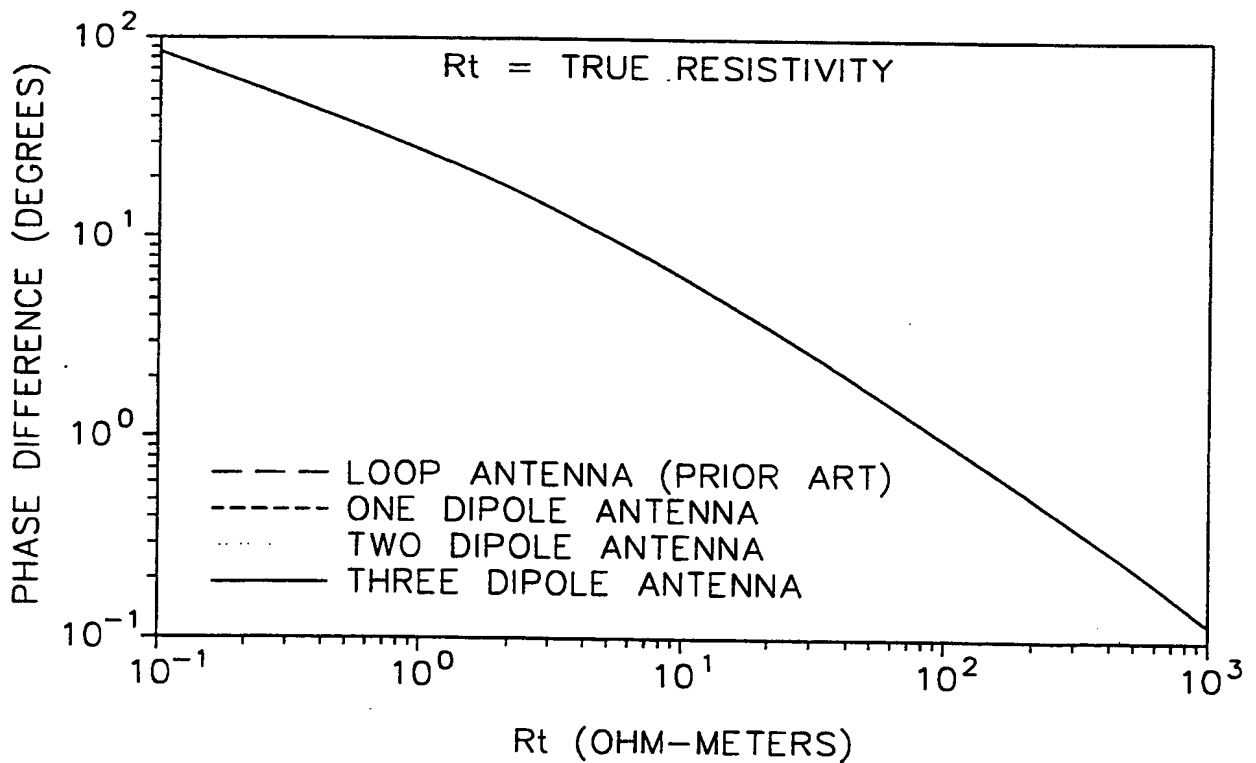


FIG. 7



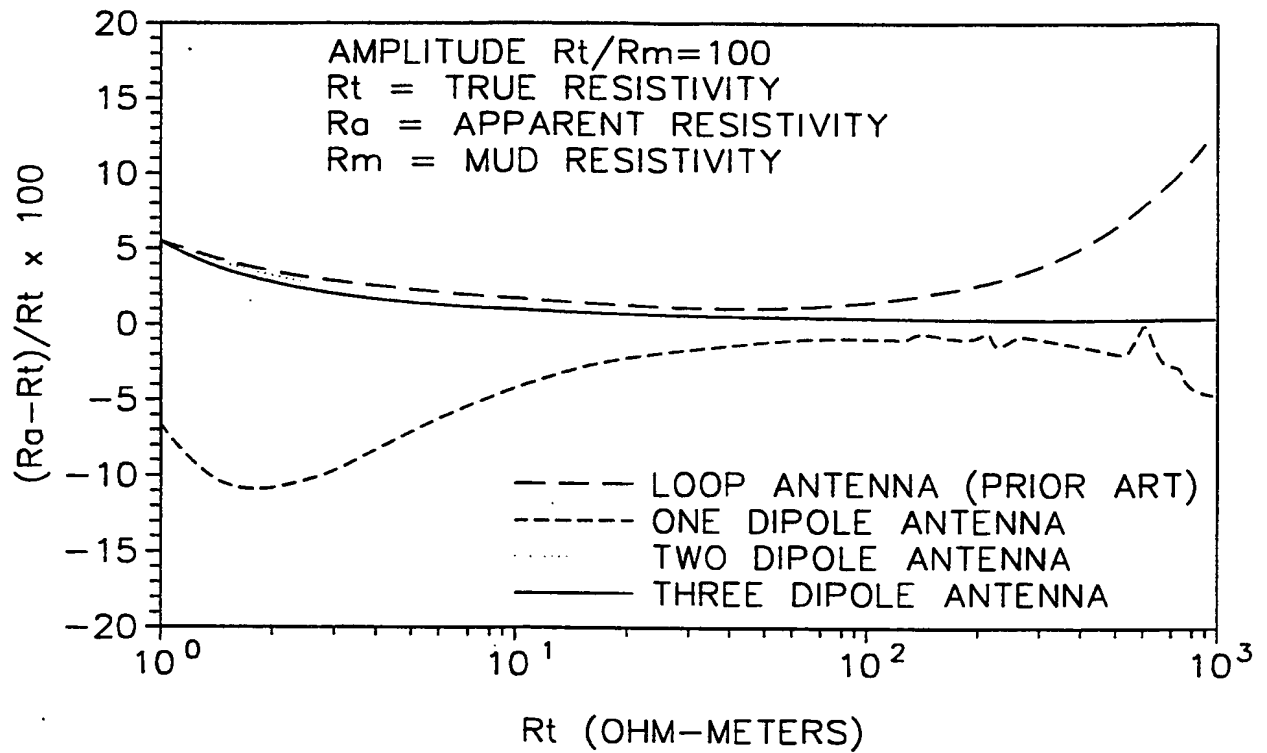


FIG. 8

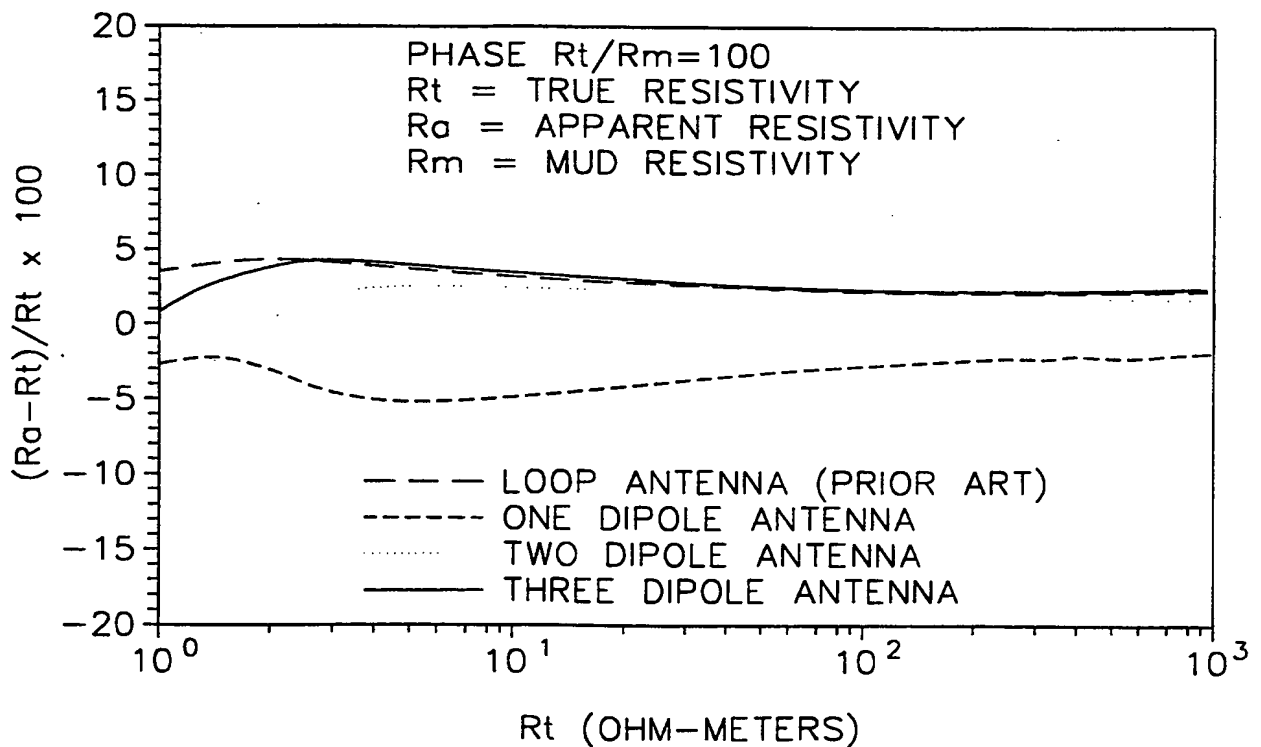


FIG. 9

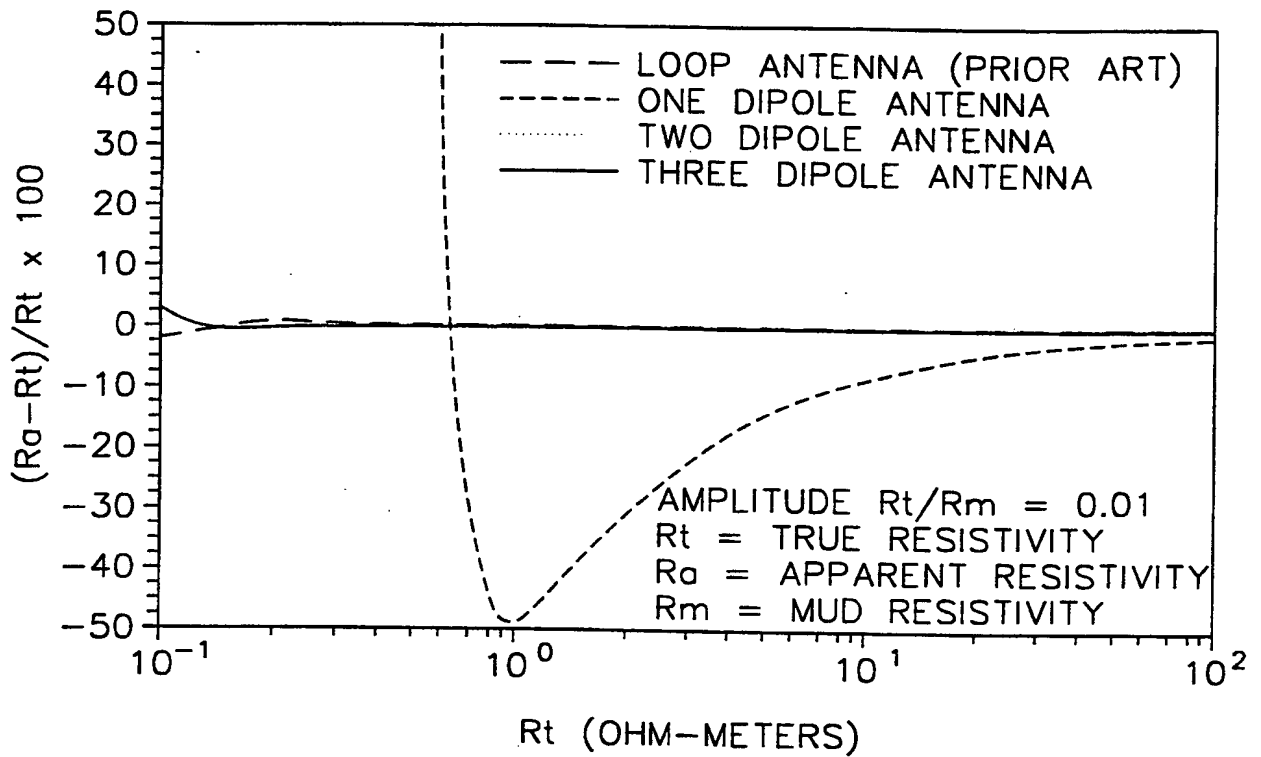


FIG. 10

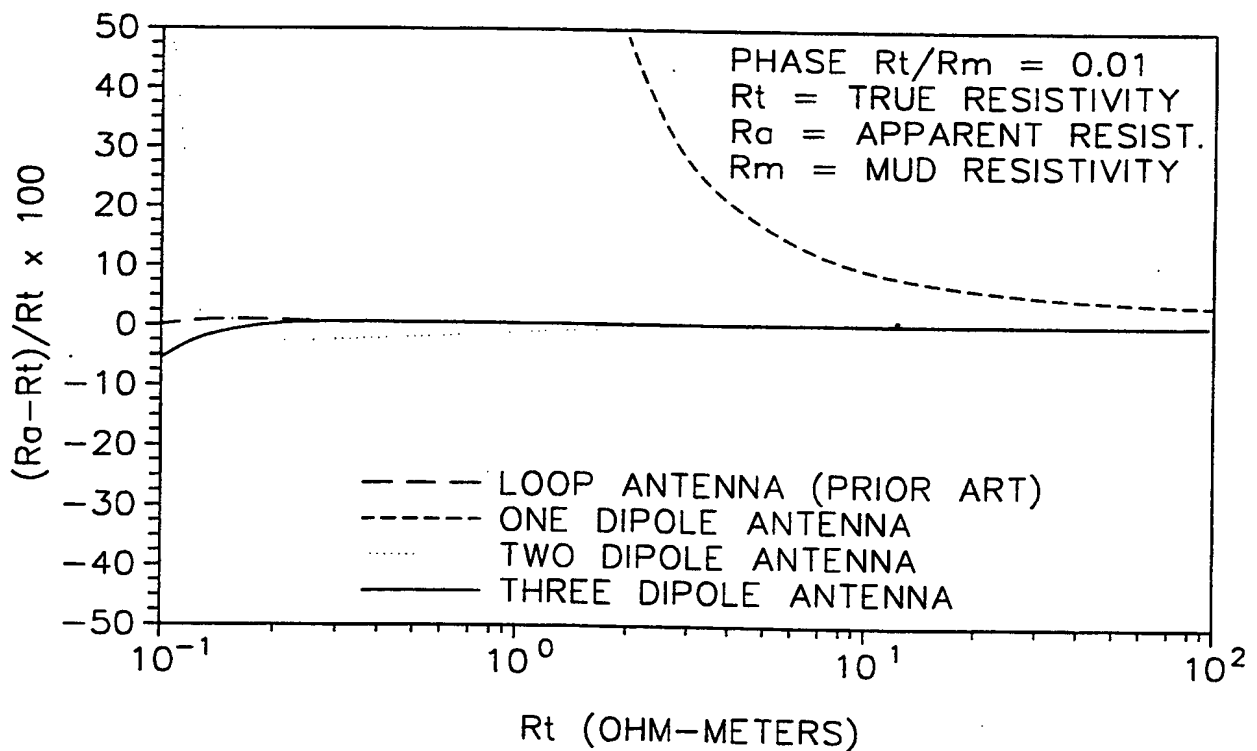


FIG. 11

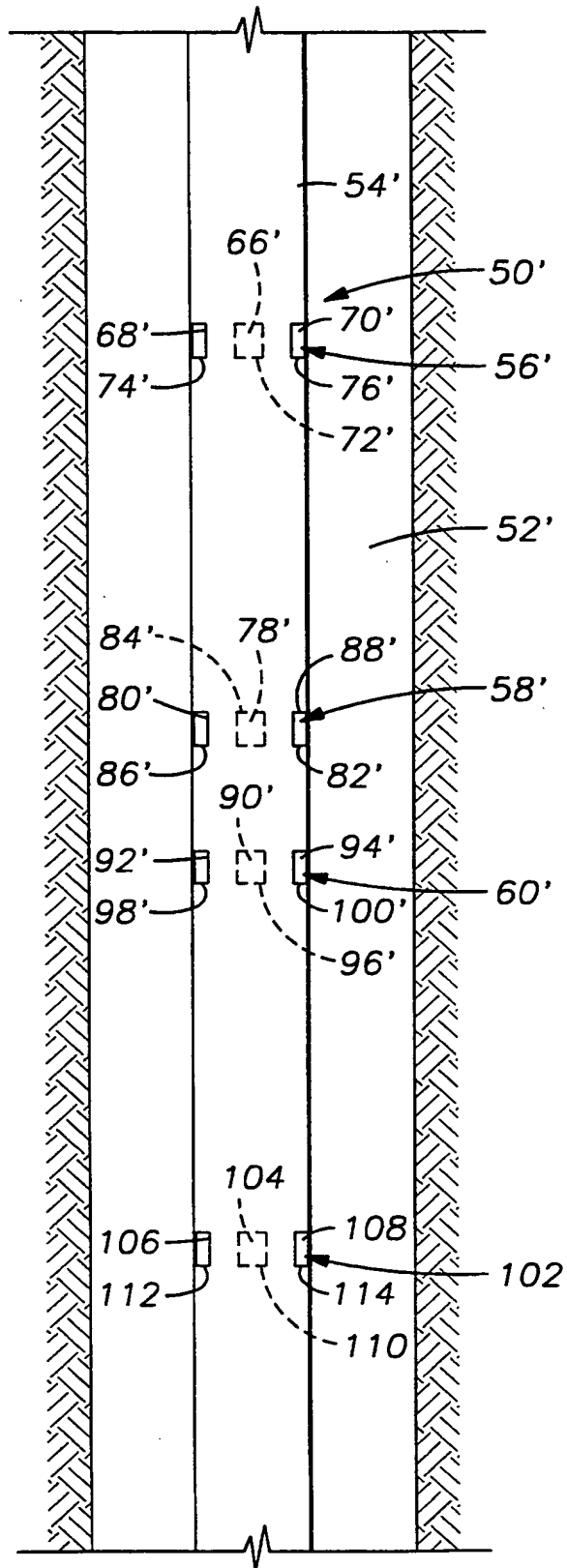


FIG. 12

## INTERNATIONAL SEARCH REPORT

Int. l. Application No

PCT/US 95/05780

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 G01V3/30

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB-A-2 268 589 (BAKER HUGHES INC) 12 January 1994 cited in the application  see abstract ---	1-12, 14-21, 23-27, 29-36
A	EP,A,0 475 715 (BAKER HUGHES INC) 18 March 1992 see abstract; figure 1 ---	1
A	US-A-4 704 581 (CLARK BRIAN) 3 November 1987 see abstract; figures 2,3 ---	1
A	FR-A-2 651 893 (TELECO OILFIELD SERVICES INC) 15 March 1991 see abstract; figures 1-3 -----	1

☐ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

## \* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&amp;" document member of the same patent family

Date of the actual completion of the international search

25 August 1995

Date of mailing of the international search report

06.09.95

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Anderson, A

# INTERNATIONAL SEARCH REPORT

Int. Application No  
PCT/US 95/05780

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A-2268589	12-01-94	US-A- 5331331 CA-A- 2097461	19-07-94 12-12-93
EP-A-0475715	18-03-92	US-A- 5089779 CA-A- 2050953 JP-A- 4233491 US-A- 5442294 US-A- 5260662	18-02-92 11-03-92 21-08-92 15-08-95 09-11-93
US-A-4704581	03-11-87	NONE	
FR-A-2651893	15-03-91	US-A- 5001675 DE-A- 4028949 GB-A, B 2236592 NL-A- 9001993	19-03-91 23-05-91 10-04-91 02-04-91